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Construction Engineering Research Laboratory

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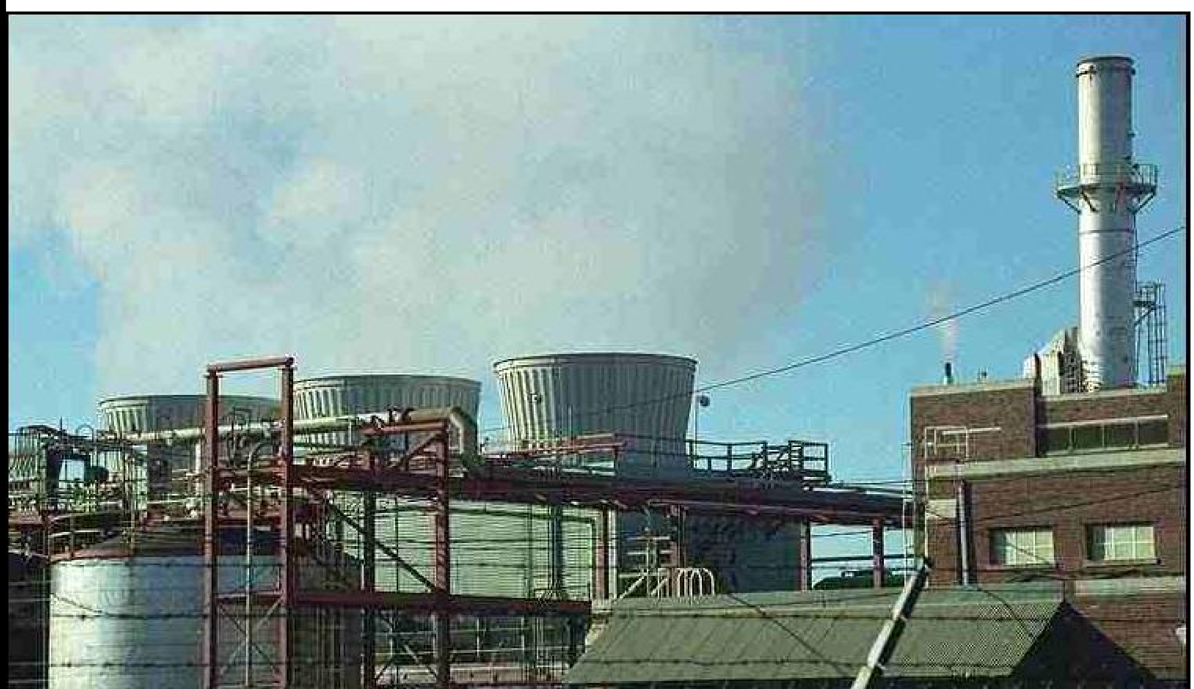
Green Chemical Treatments for Heating and Cooling Systems

Susan A. Drozdz and Vincent F. Hock

September 2006



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Green Chemical Treatments for Heating and Cooling Systems

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Final Report

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Abstract: The development of current selection and application guidance is necessary to help Army installations be “smart buyers” of water treatment for new and existing heating and cooling systems. Manufacturers continue to introduce new chemicals and treatment programs onto the market, including environmentally friendly “green” chemical products, as old products are discontinued. These products require periodic review to inform Army installations of new technological advances, and of the capabilities of chemical products available in the marketplace.

This work demonstrated and evaluated the performance of primary water treatment formulations at Fort Stewart, GA and Fort Hood, TX, using three “green” chemical technologies: (1) the cooling water inhibitor polyaspartate (PASP), (2) the cooling water biocide tetrakis (hydroxymethyl) phosphonium sulfate (THPS), and (3) a filming inhibitor made from exthoxalated soya amines (for steam line treatment). The study concluded that the three technologies were effective when used according to the recommended application guidelines.

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Preface

This study was conducted for the U.S. Army Forces Command (FORSCOM) under reimbursable Project “Performance Demonstration of Corrosion Control and Prevention.” The technical monitors were William Timmerman and Daniel Copeland, Fort McPherson, GA.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigators were Vincent F. Hock and Susan A. Drozdz. Additional technical review was provided by Paul Volkman, Installation Management Agency (IMA), Martin Savoie is Chief, CEERD-CF-M, and Michael Golish is Chief, CEERD-CF. The Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan and the Director of ERDC is Dr. James R. Houston.

1 Introduction

1.1 Background

The development of up-to-date selection and guidance is necessary to help Army installations be “smart buyers” of water treatment chemicals for new and existing heating and cooling systems. The lack of current and consistent guidelines has resulted in poor control of water treatment at many facilities. Poor control has resulted in reduced system reliability and efficiency, and also in increased maintenance costs due to premature failure of systems and components. Specifically, treatment for cooling towers, steam boilers, condensate return systems, and closed heating and cooling systems (including central plant heating and cooling systems, and building HVAC systems) needs to be addressed.

Manufacturers continue to introduce new chemicals and treatment programs onto the market, and old products have been discontinued. A significant number of new chemical water-treatment formulations have been introduced in the past several years, most notably in the areas of: (1) phosphonates and phosphonate alternatives and new, highly effective polymers for scale inhibition, (2) microbiocides for inhibition of bacteria and algae, and (3) new formulations for corrosion inhibition. Furthermore, there has been an increased interest and emphasis on environmentally friendly (“green”) chemicals. The term “environmentally friendly” refers to the environmental persistence of the chemical, and to the environmental impact of the production of the compound and eventual disposal of the spent chemical mixture.

The U.S. Army Corps of Engineers (USACE) and Army have not evaluated these new chemicals in over 10 years. Therefore, Army installations may be uninformed as to new treatment technologies. This work was undertaken to test the performance of primary water treatment formulations at Fort Stewart, GA and Fort Hood, TX, using three “green” chemical technologies:

1. The cooling water inhibitor polyaspartate (PASP)
2. The cooling water biocide tetrakis (hydroxymethyl) phosphonium sulfate (THPS)
3. A filming inhibitor made from exthoxalated soya amines (for steam line treatment).

1.2 Objectives

The objectives of this work were to test and evaluate current state-of-the-art treatment schemes using environmentally friendly "green" technologies, to confirm the effectiveness of selected treatment programs in field installations, and to make recommendations that may contribute to the development of updated guidelines for chemical treatment programs using those technologies in heating and cooling systems.

1.3 Approach

1. Operating system data for the studied systems were acquired and analyzed, including field service tests and monthly water samples.
2. Cooling Water Inhibitor Formula G-C 2610 was used at Fort Hood and Fort Stewart at a prescribed total inhibitor treatment dosage level of 100-150 ppm. Secondary additives were used for mild steel corrosion and scale protection. A small amount of molybdenum was added to track dosage levels. Two sets of corrosion coupons were exposed and analyzed to support the in-plant corrator corrosion readings in both the cooling systems and the boiler condensate. Corrator probes were copper and mild steel in cooling waters and mild steel only in the boiler condensate. The Garratt-Callahan Lab tested for metals to supplement the results of the corrosion coupons.
3. A cooling water biocide (Garratt-Callahan formula 3004) was fed two times per week for bio control. Microbial monitoring for algae was done visually (using pictures), and for bacteria using Sani-Check bacteria and fungi (BF) dip slides.
4. A biodegradable filming inhibitor, Garratt-Callahan 4055, was applied to the steam line for corrosion control. Two sets of corrosion coupons were exposed and analyzed to support the in-plant corrator corrosion readings in both the cooling systems and the boiler condensate. Laboratory tests were done for metals to supplement the results of the corrosion coupons.
5. Results were recorded and analyzed, conclusions were drawn, and recommendations formulated to supplement updated guidelines for chemical treatment programs using those technologies in heating and cooling systems.

1.4 Scope

Field measurements during this project were taken during normal daily operations at Fort Stewart and Fort Hood, and were done to minimize possible inconvenience to installation personnel. For example, Fort Hood and Fort Stewart requested that the equipment not be reopened for the project, as preventative maintenance had already been performed, and minimal disruption was a major consideration with the project. While such necessary accommodation may have limited the ability to visually inspect the results of the subject chemical treatments, it did not compromise the integrity of the instrumental measurements that form the basis for the study's resulting conclusions and recommendations.

1.5 Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) through URL:

http://www.cecer.army.mil

2 Experimental Procedure

Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) and the Garratt-Callahan Company developed chemical formulations based on products considered to be more environmentally friendly than the cooling and boiler products routinely used in industry today. This study tested three primary water treatment formulations using Green Chemical Technologies.

2.1 Cooling Water Inhibitor

ERDC-CERL and Garratt-Callahan formulated a method of condenser water treatment with a key ingredient being polyaspartate (PASP). Polyaspartic acid was the 1996 Presidential Green Chemistry Challenge Award Winner, and has proven to be an excellent dispersant and crystal modifier. This product is a water-soluble, biodegradable dispersant that is very environmentally friendly and functions well in condenser water treatment formulations. Garratt-Callahan developed two formulations with this ingredient (formula G-C 2600 and formula GC 2610).

Formula G-C 2600 was developed for supply waters with moderate hardness and alkalinity. Formula G-C 2610 was developed for waters with high hardness and high alkalinity. Formula G-C 2610 was used at Fort Hood and Fort Stewart, at a prescribed total inhibitor treatment dosage level of 100-150 ppm. Secondary additives included benzotriazole (BZT) for copper corrosion protection and two phosphonates, 2-Phosphonobutane-1,2,4-Tricarboxylic Acid (PBTC), and 1-Hydroxyethane-(1,1-di-phosphonic acid) (HEDP), for mild steel corrosion and scale protection. A small amount of molybdenum was added to track dosage levels.

2.2 Cooling Water Biocide

The second product evaluated was the cooling water biocide tetrakis (hydroxymethyl) phosphonium sulfate (THPS). THPS won the Presidential Green Chemistry Challenge Award in 1997. The recommended treatment level is below that which would be toxic to fish. In addition, THPS rapidly breaks down in the environment through hydrolysis, oxidation, photodegradation, and biodegradation. Also, because THPS is halogen-free, and does not contain volatile organic compounds, it does not contribute to dioxin or adsorbable organically bound halogens (AOX) formation.

This single product is Garratt-Callahan formula 3004, which was fed two times per week for bio control. Garratt-Callahan formula 3004 is classified as a broad spectrum, non-foaming microbiocide that is not affected by hard water when used at recommended levels. It may be used to control aerobic and anaerobic bacteria, especially the sulfate reducing bacteria. It is compatible with corrosion and scale inhibitors and with other non-oxidizing biocides. However, it is not compatible with oxidizing biocides and should not be applied in closed loops where sulfites and bisulfites are used as oxygen scavengers.

Note that, normally, two biocides are applied to cooling systems since it is rare for any one material to provide equal performance against both algae and bacteria. The overall synergistic effect is reduced when only one material is applied. Generally, biocides are rated in their effectiveness against all organism classifications; that same analysis is used here.

Microbial monitoring for algae was done visually (using pictures), and for bacteria using Sani-Check BF dip slides. “Good control” of aerobic bacteria was considered to be 500,000 organisms/ml or less and “excellent control” was considered to be 100,000 organisms/ml or less. The only acceptable count for anaerobic bacteria is zero organisms/ml, which was tested with the use of the Sani-Check anaerobic test kit, commonly used in industry. The cooling towers were also physically inspected during the evaluation process.

The product was found to be particularly effective against bacteria. It will be important to supplement this effective bactericide with a non-oxidizing material that has been proven to be very effective in preventing algae growth. Obtaining a representative water sample in a cooling tower is no easy task. However, the fact that the bacteria counts were very low raised the question of whether the product would also be effective against the potentially deadly *Legionella pneumophila* bacterium, which causes Legionnaire’s Disease.

2.3 Steam Line Treatment

The third and final product in the Green Chemistry project was a filming inhibitor made from exthoxalated soya amines. The specification for this product was the basis for Garratt-Callahan formula 4005, and was applied both at Fort Hood and at Fort Stewart. This product is used to control both oxygen and carbon dioxide corrosion in steam lines by forming a monomolecular protective film barrier on metal surfaces.

Although more toxic than the two Presidential Award Winners, this material is inherently biodegradable; a closed bottle test showed a 42 percent biodegradability at day 28 and a 54 percent biodegradability at day 42. The normal dosage is 2 to 3 lb of active ingredient per 100,000 lb of steam generated. (Overfeed of the material may cause foaming.) The product is applied directly to the steam header. The initial startup dosage must be minimal to reduce loose iron put in solution as the film-forming process cleans the condensate line during film development.

The additional oxygen protection provided by a film forming material (as compared to conventional neutralizing amines) is a very important characteristic of this product since it can still be effective when steam boilers are put on stand-by, with the resulting significant decrease in steam line temperature and pressure. Overall corrosion data was good, although there were spikes when the dosage was not maintained and when the condensate line was not full (at which time the corrator tip was not totally submerged in condensate).

2.4 Data Acquisition

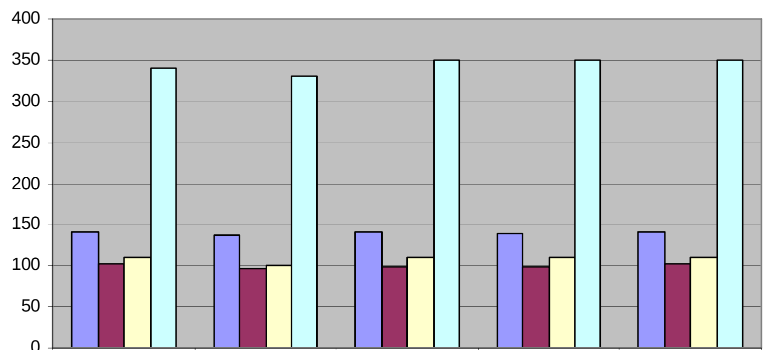
For any research project to develop accurate conclusions, a significant amount of actual operating system data is required. The sources of this data include field service tests and monthly water samples. Two sets of corrosion coupons were exposed and analyzed to support the in-plant corrator corrosion readings in both the cooling systems and the boiler condensate. Corrator probes were copper and mild steel in cooling waters and mild steel only in the boiler condensate. The Garratt-Callahan Lab tested for metals to supplement the results of the corrosion coupons. Table 1 lists the corrosion standards that were used.

Table 1. Standard corrosion control guidelines.

Coupon Metal	Good Control	Excellent Control	Out of Control
Mild Steel	< 5 mpy	<2 mpy	>6 mpy
Copper	<0.2 mpy	<0.1 mpy	>0.3 mpy
304 SS	<1 mpy	<0.5 mpy	>2 mpy
Aluminum	<0.8 mpy	<0.4 mpy	>1.5 mpy
Galvanized	<3 mpy	<1.5 mpy	>4 mpy

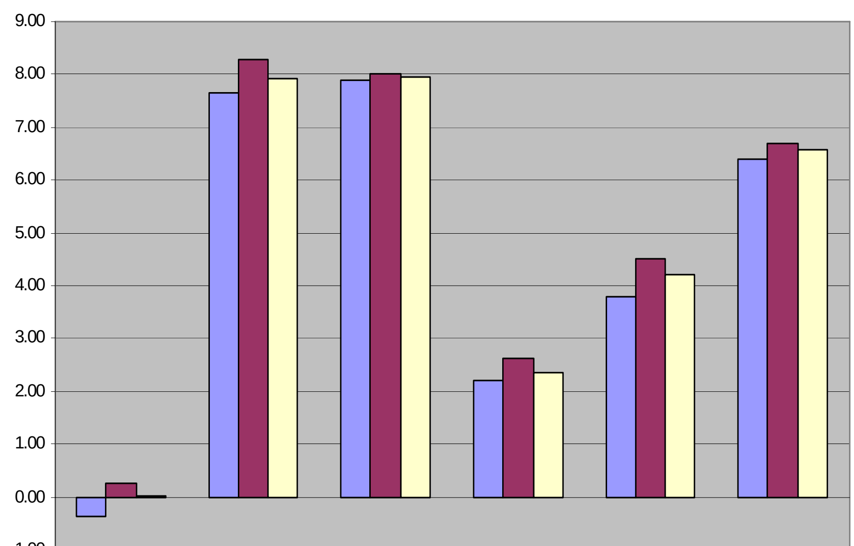
2.4.1 Fort Hood Supply Water

The supply water at Fort Hood is consistently a moderately hard water supply that is low in silica. Figures 1 and 2 show the laboratory supply water analyses and resulting measures of Calcium Hardness, Total Alkalinity (LSI/RSI),* and pH levels.



	7/23/2002	8/28/2002	9/26/2002	10/9/2002	10/31/2002
Supply H2O H	141	137	141	139	142
Supply H2O CaH	102	97	99	99	102
Supply H2O T Alk	110	100	110	110	110
Supply H2O SC	340	330	350	350	350

Figure 1. Fort Hood supply water (analysis measures).



	Supply LSI	Supply RSI	Supply pHs	Tower LSI	Tower RSI	Tower pHs
Min	-0.38	7.65	7.90	2.19	3.78	6.40
Max	0.25	8.28	8.00	2.62	4.51	6.70
Ave	0.01	7.93	7.94	2.37	4.20	6.57

Figure 2. Fort Hood supply water (analysis min/max/avg.).

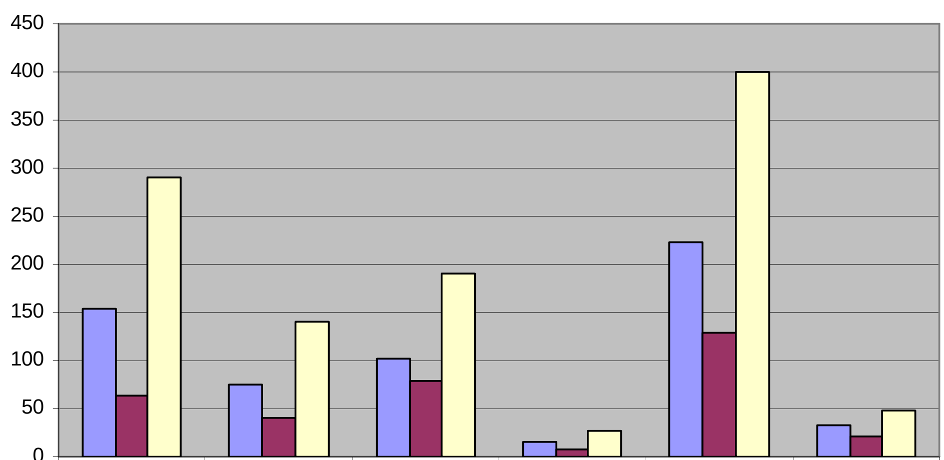
* Langlier's Saturation Index (LSI); Ryznar's Stability Index (RSI).

2.4.2 Fort Stewart Supply Water

The Fort Stewart water supply is subject to a wide range of dissolved solid concentrations, reflected in all key operating parameters (Figures 3 and 4). Note the silica change from 21 ppm to 48 ppm. Silica was a key component in previous deposit analyses. The calcium hardness swing was from a low of 40 ppm to a high of 140 ppm, with the total hardness varying from a low of 64 ppm to a high of 290 ppm. Typically, the magnesium ion reacts with the silica to form magnesium silicate. The magnesium hardness may be determined by subtracting the calcium hardness from the total hardness.

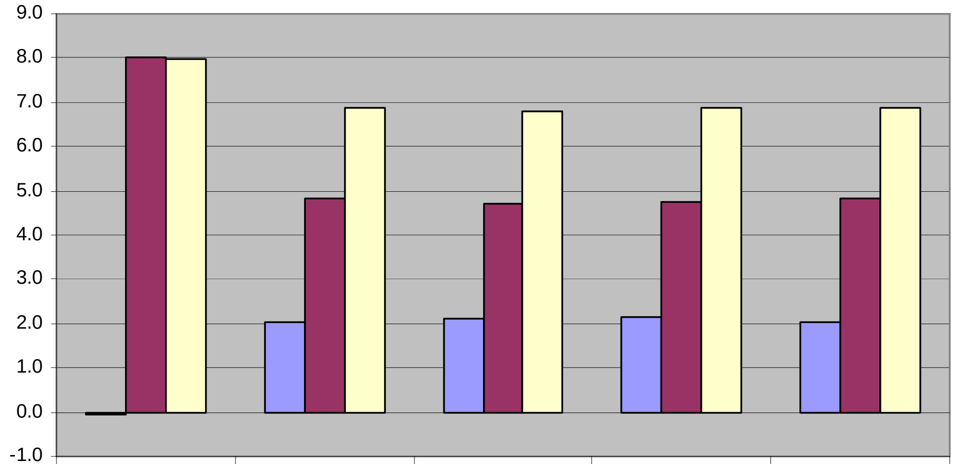
It is difficult to use the chloride ion as a hardness balance when the supply water chloride varies from a minimum of 8 ppm to a high of 26 ppm. Even the total alkalinity had a swing from 78 ppm to 190 ppm.

At this location, each test series had to be closely reviewed and analyzed for the tendency to precipitate either calcium carbonate (scale) or magnesium silicate deposits. If necessary, the total conductivity control range must be lowered to prevent exceeding solubility levels and the reaction of calcium, magnesium, silica, and alkalinity ions.



	Supply H	Supply CaH	Supply T Alk	Supply Cl	Supply SC	Supply SiO2
Average	154	76	103	16	224	34
Minimum	64	40	78	8	128	21
Maximum	290	140	190	26	400	48

Figure 3. Fort Stewart supply water (dissolved solids, min/max/avg.).



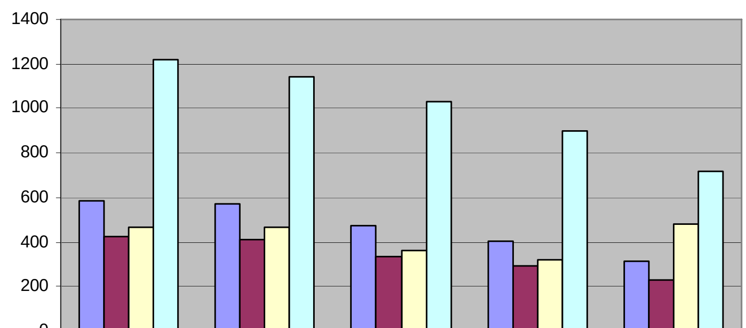
	Supply MU	Tower 1	Tower 2	Tower 3	Tower 4
Ave LSI	-0.1	2.0	2.1	2.1	2.0
Ave RSI	8.0	4.8	4.7	4.7	4.8
Ave pHs	8.0	6.9	6.8	6.9	6.9

Figure 4. Fort Stewart supply water (avg. dissolved solids, all towers).

3 Results

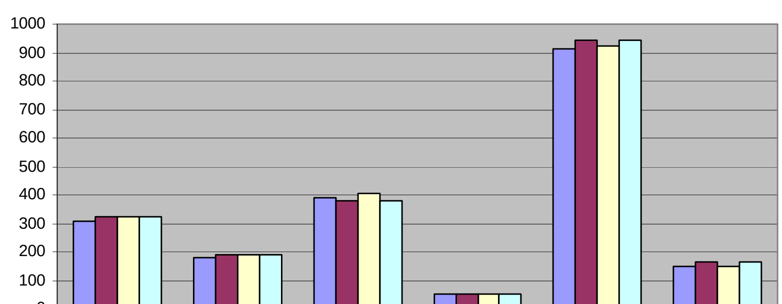
3.1 Cooling Tower Analyses

Fort Hood cooling tower water control has been very good. Changes were generally the result of biocide programming to improve biocide effectiveness (Figure 5). Fort Stewart tower residuals reflect significant fluctuation, primarily due to changes in the makeup supply (Figure 6). However, the advanced automation equipment did a very good job in maintaining established conductivity levels.



	7/23/2002	8/28/2002	9/26/2002	10/9/2002	10/31/2002
Tower H	588	574	472	407	311
Tower CaH	426	408	334	290	228
Tower Total Alk	470	470	360	320	480
Tower SC	1220	1140	1030	900	720

Figure 5. Laboratory results for the Fort Hood cooling towers.



	Tower H	Tower CaH	Tower Total Alk	Tower Cl	Tower SC	Tower SiO2
Tower 1	310	182	391	52	914	148
Tower 2	323	189	379	50	942	162
Tower 3	323	188	404	51	922	150
Tower 4	323	189	379	50	942	162

Figure 6. Field analysis for the Fort Stewart cooling towers.

3.1.1 Scale Control

The concentration of the scale inhibitor is monitored by way of the molybdate residual, recommended at 0.5 to 0.75 parts per million (ppm) Mo. This corresponds to 100 to 150 ppm total treatment. Figures 7 and 8 show the excellent chemical molybdate control at both facilities.

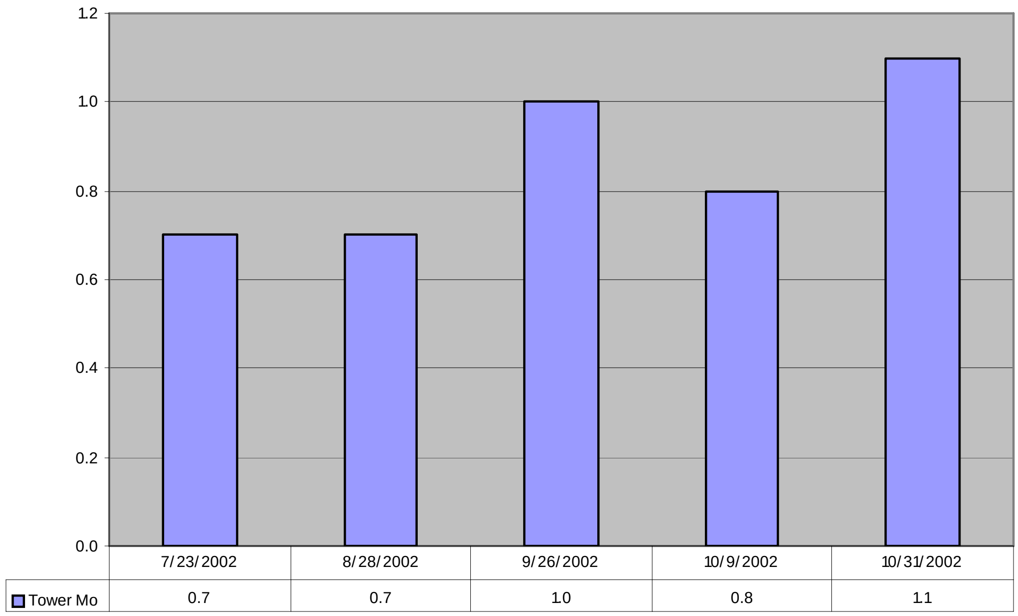


Figure 7. Molybdate analysis of the Fort Hood cooling tower.

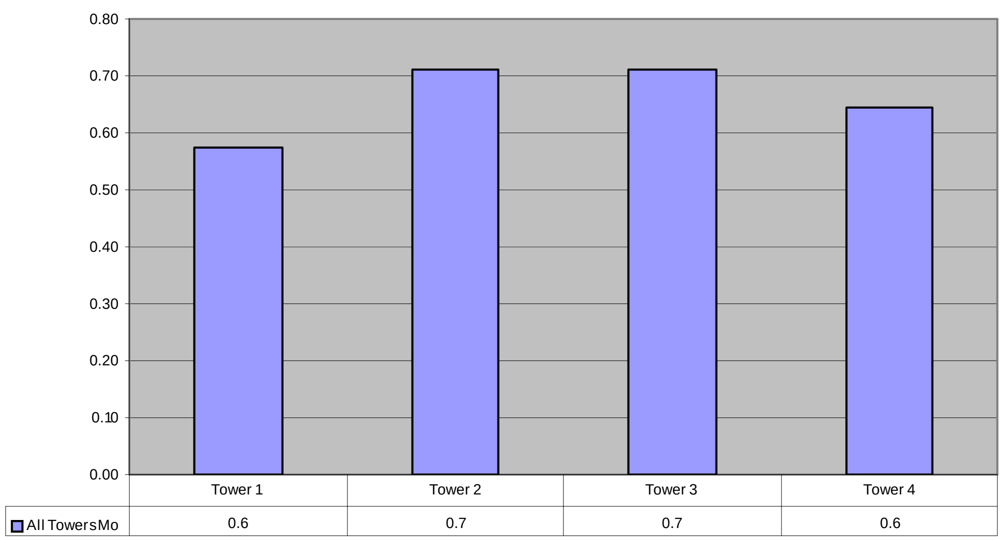


Figure 8. Average molybdenum for all towers at Fort Stewart.

Another factor in the scale control process is the control of dissolved solids. Without dissolved solids control (specific conductivity), the solubility of specific ions is exceeded. When this occurs, deposition will result, even with proper chemical levels. Again Figures 9 and 10 show that the automation has provided good overall control. In addition to the specific conductivity overview, some supply waters contain an abnormal amount of calcium, total alkalinity, or silica. Also, where sulfuric acid is used for pH control, consideration must be given to the sulfate content.

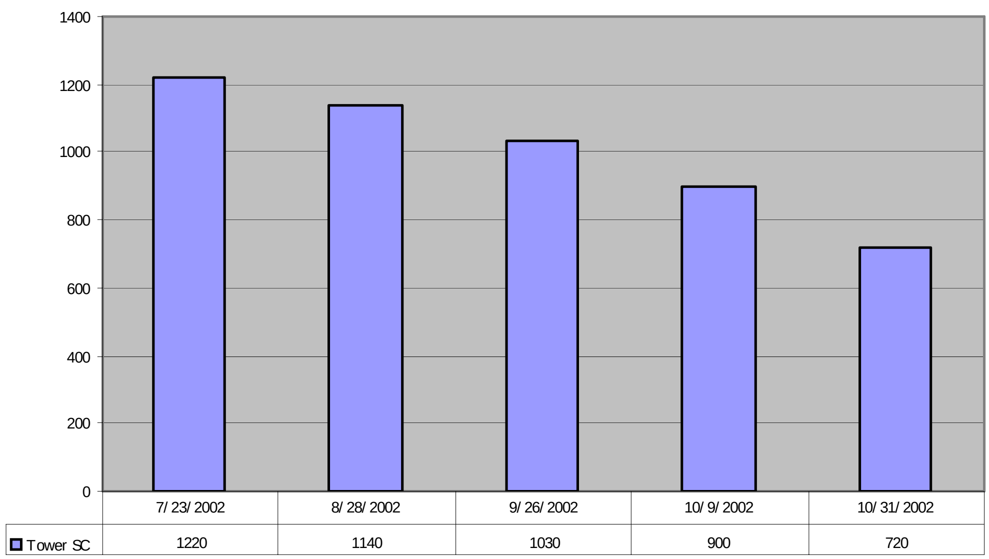


Figure 9. Cooling tower conductivity at Fort Hood.

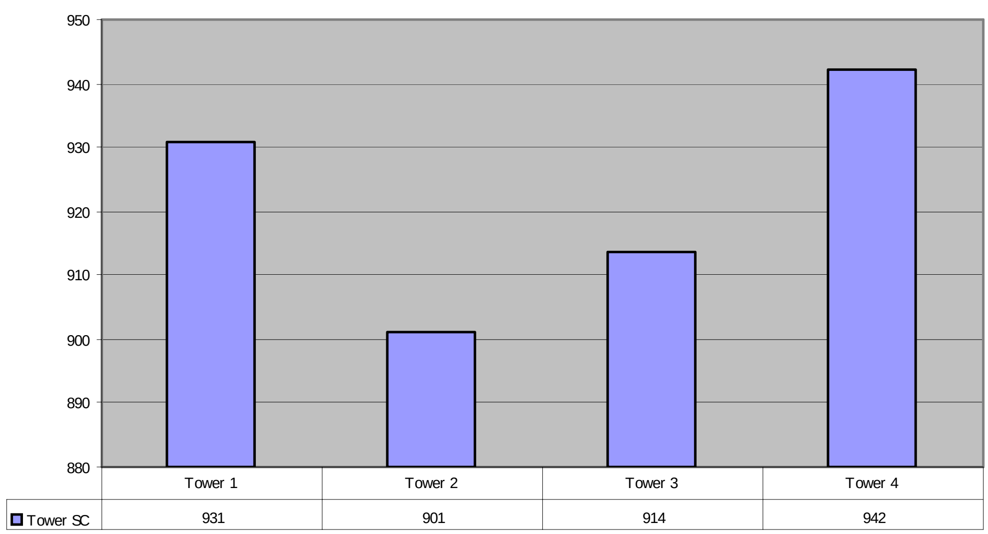


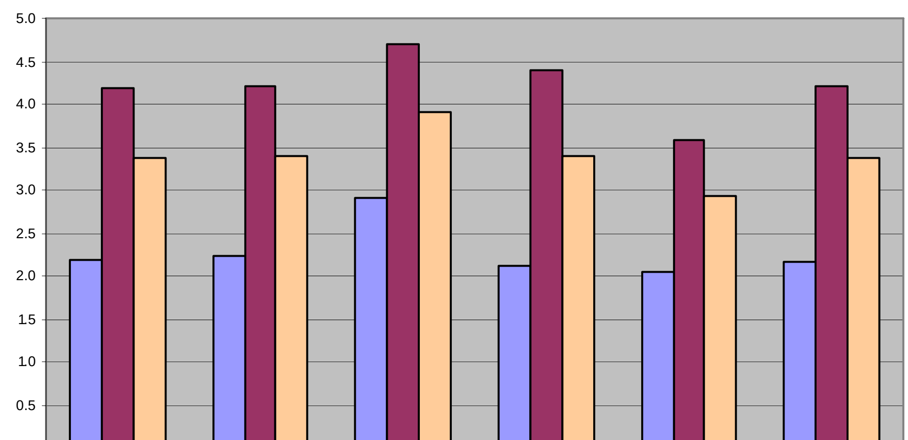
Figure 10. Average conductivity of all cooling towers at Fort Stewart.

In a non-acid program, the combined total of calcium ions and alkalinity (carbonate, bicarbonate, and hydroxide ions) should not exceed 900 ppm. The exception to this would be when silica levels are high, such as at Fort Stewart. The absolute maximum level of silica in cooling towers is 180 ppm, with control levels normally established at 150 ppm to provide some safety margin. A calcium silicate deposit, which was noted with the initial deposit, is not very responsive to the typical sulfamic or hydrochloric acid flush. If the thickness of the deposit is extensive, only hydrofluoric acid will solubilize the calcium silicate, and this acid is extremely dangerous to use.

Deposition in heat exchangers is not only a burden to mechanical maintenance personnel, but is also very costly as deposits decrease the heat transfer process and this increases energy consumption.

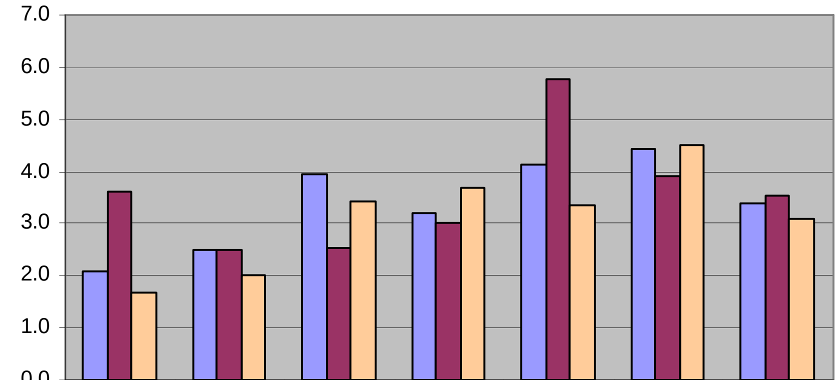
3.1.2 Cycles of Concentration

As water evaporates in the cooling process, the minerals remain. This accumulation of minerals, when compared to the minerals in the supply water, is referred to as “cycles of concentration.” The comparison of total hardness, calcium hardness, total alkalinity, chlorides, specific conductivity, total dissolved solids (TDS), and silica (Fort Stewart only) in the tower water, when divided by the same element in the supply water, yields the “cycles of concentration” shown in Figures 11 and 12.



	Total Hardness	Calcium Hardness	Total Alkalinity	Chloride	Specific Conductivity	Silica
Minimum	2.2	2.2	2.9	2.1	2.1	2.2
Maximum	4.2	4.2	4.7	4.4	3.6	4.2
Average	3.4	3.4	3.9	3.4	2.9	3.4

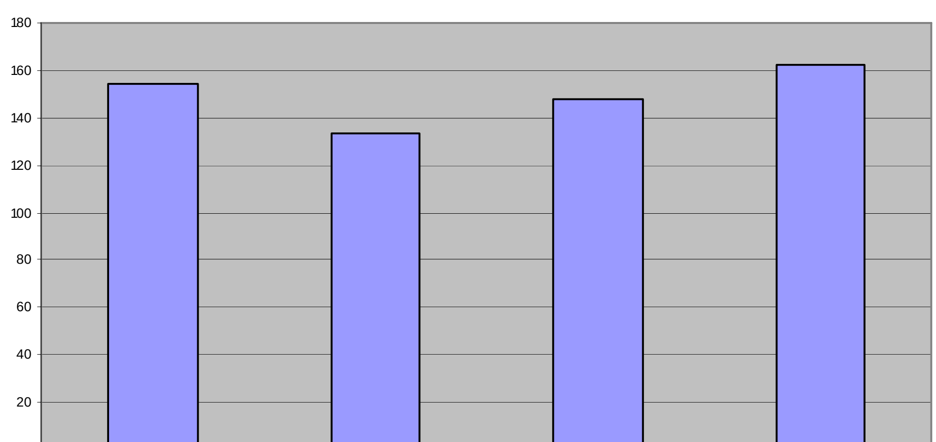
Figure 11. Cycles of concentration at Fort Hood.



	H Cycles	CaH Cycles	T Alk Cycles	Cl Cycles	SC Cycles	SiO2 Cycles	Ave All Cycles
Average All Towers	2.1	2.5	3.9	3.2	4.1	4.4	3.4
Minimum Towers	3.6	2.5	2.5	3.0	5.8	3.9	3.6
Maximum Towers	1.7	2.0	3.4	3.7	3.4	4.5	3.1

Figure 12. Cycles of concentration for all towers at Fort Stewart.

As previously mentioned, there were concerns about silica levels in the cooling water. With the change in supply water conductivity, hardness, and silica, it was necessary to maintain lower conductivity residuals in the cooling towers than would normally be expected. Since it was known that deposition of silica had previously been a primary element in the composition, researchers did not want to allow the silica residual to exceed 150 ppm. For the most part, the automatic "bleed and feed" system provided the control needed to operate within these operating parameters. Figure 13 shows the average silica levels for each tower at Fort Stewart.



	Tower 1	Tower 2	Tower 3	Tower 4
Tower SiO2	154	134	148	162

Figure 13. Average silica for all towers at Fort Stewart.

3.1.3 Bio Control

The effective control of microbiological organisms is a very important part of the water treatment program. Biological control primarily consists of bacteria and algae control. It is rare that one material alone can control both classes of organisms.

In the project evaluation process, a decision was made to use THPS (Garratt-Callahan formulation G-C 3004) on a "standalone" basis, out of a concern that the typical dual biocide approach would make it difficult to evaluate the THPS' performance. Microbial monitoring for algae was done visually (using pictures), and for bacteria using Sani-Check BF dip slides. Although a measurement of 500,000 organisms/ml or less is considered "good control" of aerobic bacteria is, and 100,000 organisms/ml or less is considered "excellent control," the only truly acceptable count for anaerobic bacteria is zero organisms/ml (which is tested with the Sani-Check anaerobic kit). Tables 2 and 3 list the results of the bacteria tests at Fort Hood and Fort Stewart. The evaluation process also included physical inspection of the cooling towers, with pictures, for algae control.

The THPS product was classified as a broad spectrum material, used primarily to control aerobic and anaerobic bacteria. For the most part, the material was very effective in the control of bacteria. Graphs in Figures 14 through 17 illustrate the bacteria effectiveness of THPS at Fort Stewart. Similarly, Figure 18 shows bacteria control at the Fort Hood cooling tower.

Recall that bacteria counts show only planktonic (free-floating) bacteria. Sessile bacteria are those attached to the tower, and can outnumber the planktonic bacteria. Bacteria tests are very useful in showing general trends of bio control. While not a precise method of measurement, it is generally accepted that low bacteria counts indicate a cleaner and safer system than those that show high bacteria levels. Figures 19 and 20 reflect minimal algae control at Fort Hood and Fort Stewart.

Table 2. Bacteria bio count (Fort Hood).

Date	Aerobic Bacteria	Anaerobic Bacteria
10 July 2002	10^4	0
31 July 2002	10^3	0
8 August 2002	10^3	0
20 August 2002	10^3	0

Date	Aerobic Bacteria	Anaerobic Bacteria
27 August 2002	10^4	0
5 September 2002	10^5	0
11 September 2002	10^5	0
18 September 2002	10^4	0
26 September 2002	10^3	0
2 October 2002	10^3	0
9 October 2002	10^4	0
16 October 2002	10^4	0
23 October 2002	10^5	0
31 October 2002	10^3	0
5 November 2002	10^3	0
12 November 2002	10^4	0
20 November 2002	10^3	0
27 November 2002	10^3	0

Table 3. Aerobic bacteria bio count (Fort Stewart).

Date	Tower 1	Tower 2	Tower 3	Tower 4
19 July 2002		10^3		
4 August 2002				10^4
9 August 2002			10^3	
16 August 2002	10^2			
2 September 2002			10^3	10^2
6 September 2002	10^2			
15 September 2002	10^2			
23 September 2002				10^3
1 October 2002	10^2		10^3	
8 October 2002	10^2	10^2		
18 October 2002				10^2
25 October 2002		10^3		
1 November 2002	102			
8 November 2002		10^2		
15 November 2002	10^3			

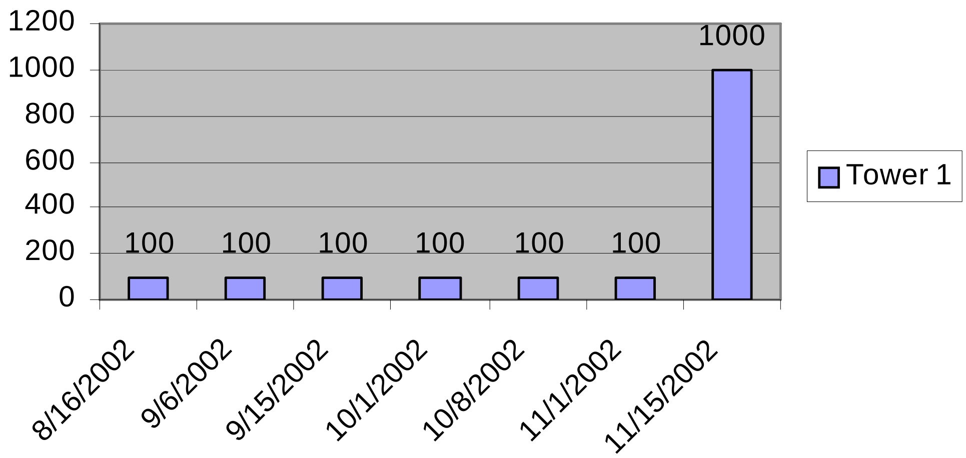


Figure 14. Fort Stewart – Tower 1.

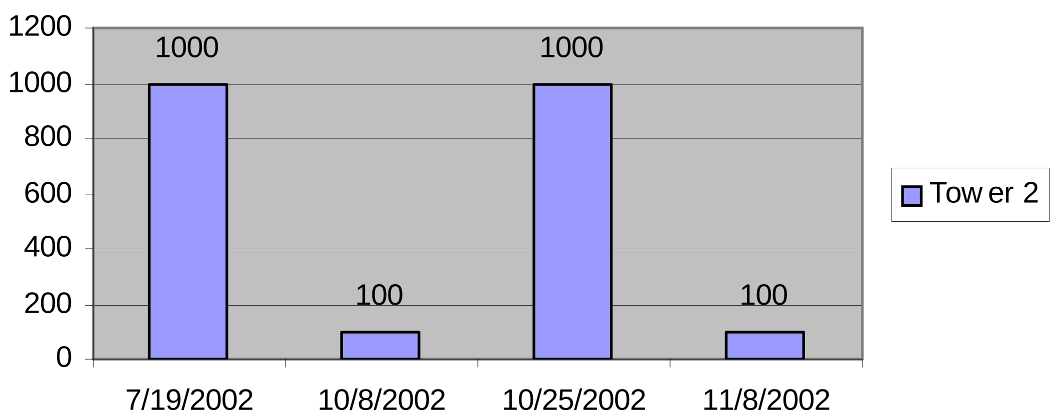


Figure 15. Fort Stewart – Tower 2.

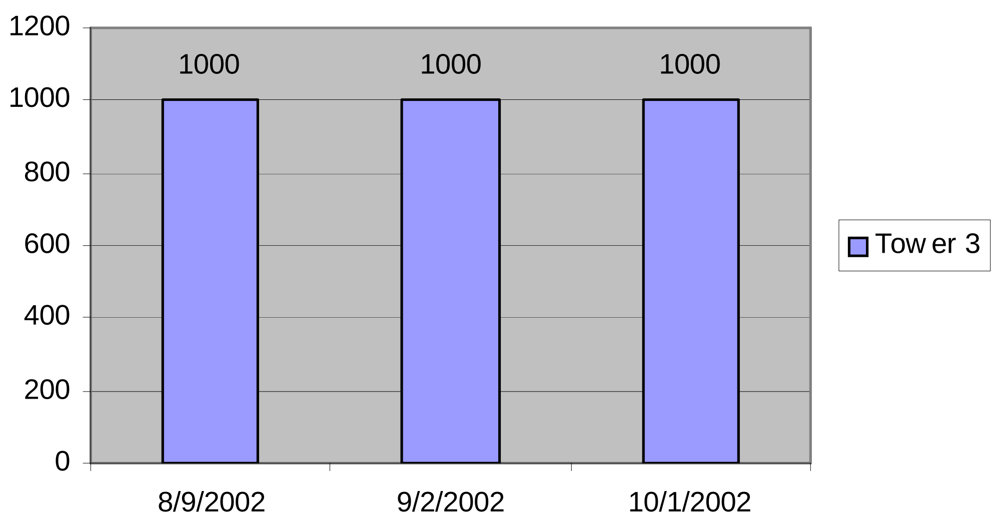


Figure 16. Fort Stewart – Tower 3.

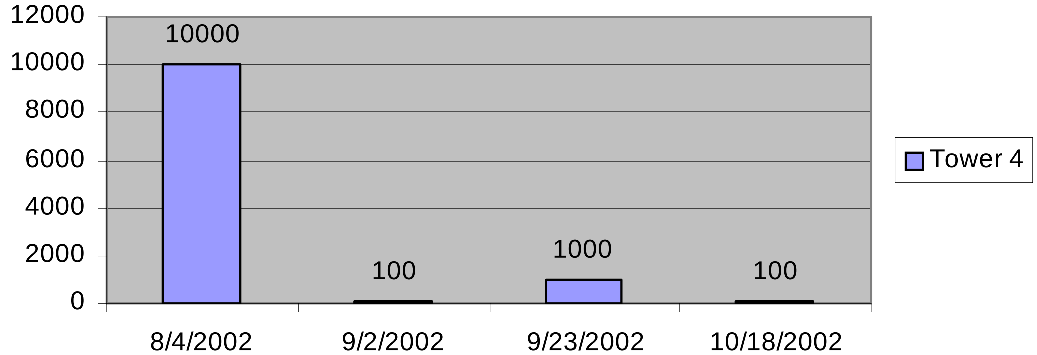


Figure 17. Fort Stewart – Tower 4.

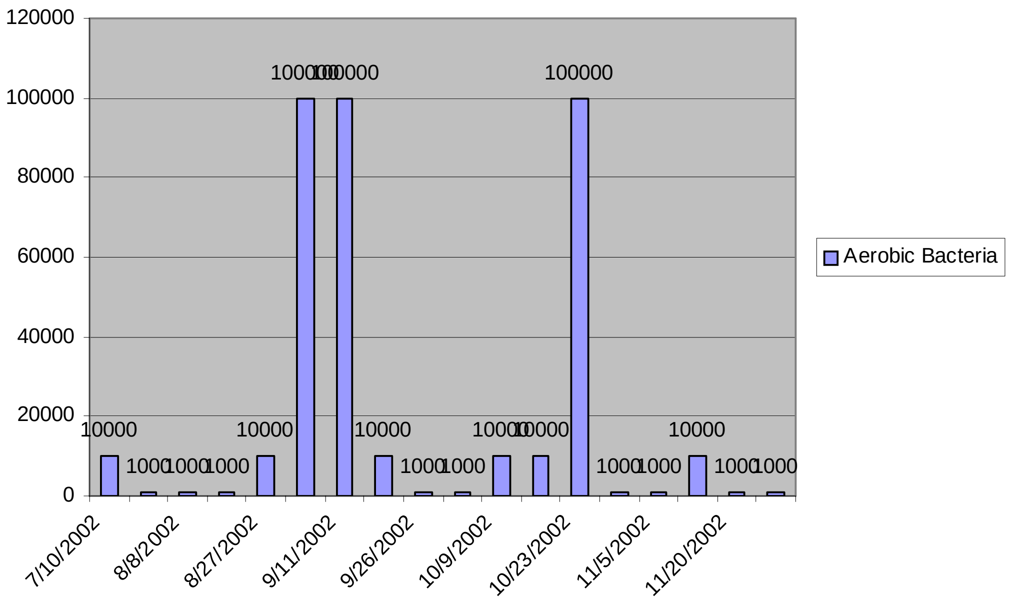


Figure 18. Fort Hood aerobic bacteria.

Figure 19. Fort Hood Sump.

Figure 20. Fort Stewart sump.

3.2 Steam Boiler Condensate

A biodegradable filming inhibitor, formulated as Garratt-Callahan 4055, was applied to the steam line for corrosion control. Figure 21 shows the tight film formation.

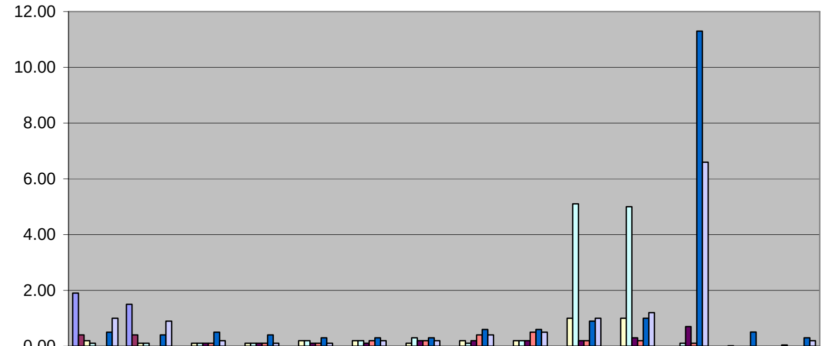
3.3 Corrosion Data

Corrosion is a natural electro-chemical process that can attack any metal or alloy under the right conditions. The Illinois State Water Survey took and verified corrosion measurements in the cooling tower water and in the boiler condensate with the use of corrosion coupons.

Measurements were also taken with a field corrator, which measures overall corrosion rates and pitting corrosion rates. Corrator probes, sometimes referred to as "automatic coupons" are used to measure loss of probe metal by measuring their change in resistance. As with coupons, probes must be in the system for a period of time to allow the probe to corrode so that accurate measurements can be made.

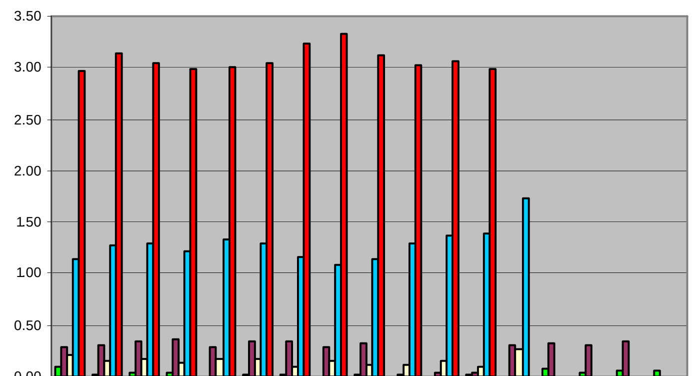
Figure 22 shows the corrosion rate of the cooling tower water and condensate at Fort Hood and Figure 23 reflects the corrosion rate for the condensate system at Fort Stewart. Overall, an average of 3 mils per year is considered "good corrosion control."

Figure 21. Filming inhibitors.



	7/31	8/8	8/27	9/5	9/11	9/18	9/26	10/2	10/9	10/16	10/23	11/12	11/20	11/27
Tower Steel Coupons - Corrosion Rate	1.90	1.50												
Tower Steel Coupons - Pitting Rate	0.40	0.40												
Tower Cu Coupons - Corrosion Rate	0.20	0.10	0.10	0.10	0.20	0.20	0.10	0.20	0.20	1.00	1.00	0.00	0.01	0.04
Tower Cu Coupons - Pitting Rate	0.10	0.10	0.10	0.10	0.20	0.20	0.30	0.10	0.20	5.10	5.00	0.10	0.00	0.00
Tower Galv. Coupons - Corrosion Rate			0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.30	0.70		
Tower Galv. Coupons - Pitting Rate			0.10	0.10	0.10	0.20	0.20	0.40	0.50	0.20	0.20	0.10		
Boiler Cond. Steel Coupon - Corrosion Rate	0.50	0.40	0.50	0.40	0.30	0.30	0.30	0.60	0.60	0.90	1.00	11.30	0.51	0.30
Boiler Cond. Steel Coupons - Pitting Rate	1.00	0.90	0.20	0.10	0.10	0.20	0.20	0.40	0.50	1.00	1.20	6.60		0.20

Figure 22. Corrator results and analyses for cooling towers and condensate at Fort Hood.



	7/12	7/30	8/04	8/09	8/16	8/23	9/02	9/06	9/15	9/23	10/8	10/11	10/25	11/01	11/08	11/15	11/26
Tower 1Copper	0.10	0.02	0.03	0.04	0.00	0.02	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.08	0.04	0.06	0.06
Tower 2 Steel	0.29	0.31	0.34	0.36	0.29	0.34	0.34	0.29	0.33	0.03	0.03	0.03	0.31	0.33	0.31	0.35	
Tower 3 Copper	0.20	0.15	0.18	0.14	0.17	0.18	0.09	0.15	0.11	0.12	0.16	0.09	0.27				
Tower 4 Steel	1.14	1.27	1.29	1.22	1.34	1.29	1.16	1.08	1.14	1.29	1.37	1.39	1.74				
Boiler Cond. Steel	2.97	3.14	3.04	2.98	3.01	3.05	3.24	3.32	3.12	3.02	3.07	2.99					

Figure 23. Fort Stewart Corrator Results.

The dosage was determined to be the key factor in the variation of corrosion results. When the ethoxalated soya amine approached 2 parts per million, the corrosion rate increased significantly. It is suggested that the material be applied at 3 parts per million of active ingredient. (A 10-percent solution would require a dosage of 30 ppm.)

Figure 24 shows a typical corrosion coupon installation and corrator. Note that the readings are only accurate when the probe tips are completely submerged in water. Sometimes this does not occur in the condensate lines. Also (very important), when taking readings with the corrator, if the pitting numbers exceed the general corrosion rate, the pitting numbers are no longer accurate.

3.4 Improved Automation Control

The advanced fully automated equipment represents a significant improvement in the application of water treatment products. The use of this state-of-the-art technology also significantly improves the safety of handling chemicals. Communication capabilities provide the opportunity to remotely monitor system performance, gather system data, and adjust operating parameters. Overall performance was very good.

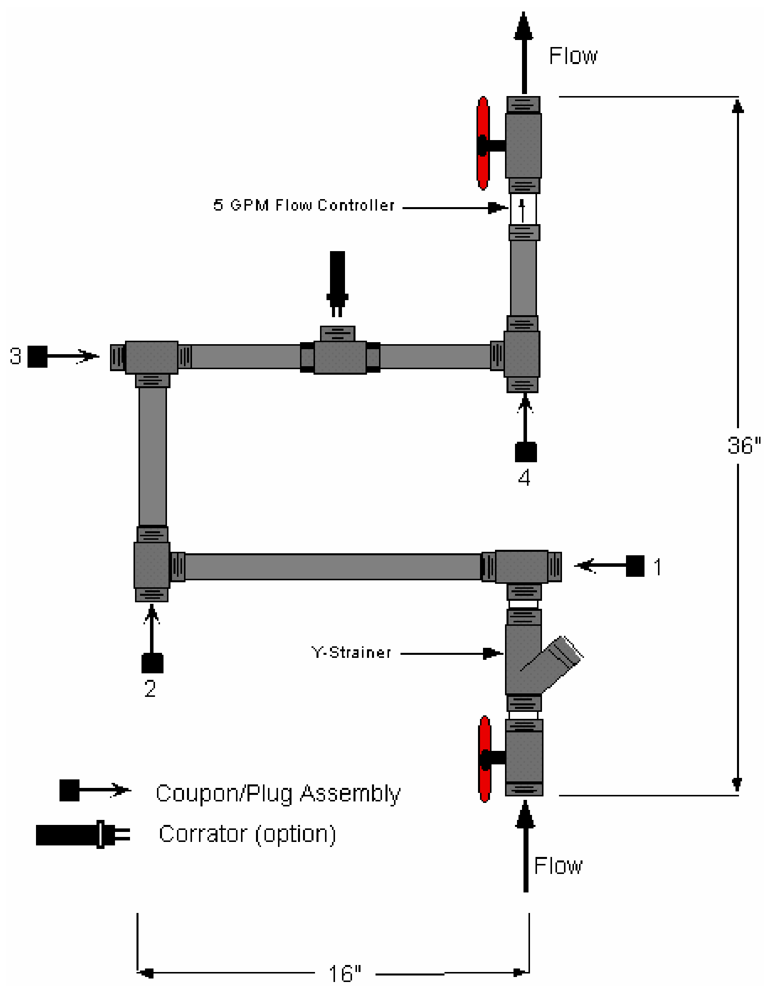


Figure 24. Corrator probe installation.

4 Conclusions and Recommendations

This study demonstrated the effectiveness of three green chemical formulations for the control of corrosion, scale, and microbiological growth in heating and cooling systems. Compared to the traditional treatments, these formulations have properties such as biodegradability that make them more friendly to the environment. The implementation of these formulations in cooling towers and steam distribution lines at Fort Hood and Fort Stewart showed that these formulations can perform well. Specific recommendations for each formulation follow.

4.1 Cooling Water Inhibitor

4.1.1 Conclusions

The application of the polyaspartate (PASP) inhibitor blend maintained the operating performance of the equipment unchanged. This study found that the product had good dispersion qualities, and that it offered the advantage of being biodegradable. A few tests were found with elevated copper residuals that may or may not be influenced by the PASP material.

When the condensers were opened at the end of the project period at Fort Hood and at Fort Stewart, the heat exchanger tubes at Fort Hood were found to be very clean and at Fort Stewart as good as, or better than, previous inspections using conventional water treatment chemicals.

4.1.2 Recommendations

Additional testing to optimize dosage is recommended with future applications.

4.2 Cooling Water Biocide

4.2.1 Conclusions

The biocide application of tetrakis hydroxymethyl phosphonium sulfate (THPS) was found to be particularly effective against bacteria; it was found to provide good control of both aerobic and anaerobic bacteria.

4.2.2 Recommendation

The recommended dosage for THPS of 360 ppm is higher than some of the other non-oxidizing biocides. Since THPS had limited success with algae control, this study recommends supplementing the use of THPS with an alternate non-oxidizing algaecide.

4.3 Steam Line Treatment

4.3.1 Conclusions

The filming inhibitor used for condensate corrosion control, an ethoxalated soya amine, showed considerable promise due to the ease of application and strong film formation. The additional oxygen protection provided by a film forming material (as compared to conventional neutralizing amines) is a very important characteristic of this product since it can still be effective when steam boilers are put on stand-by, with the resulting significant decrease in steam line temperature and pressure. Overall corrosion data was good, although there were spikes when the dosage was not maintained and when the condensate line was not full (at which time the corrator tip was not totally sub-merged in condensate). The advantage of this product, as compared to a neutralizing amine, is the additional protection against oxygen corrosion. In addition, this product is not a suspected carcinogen like some neutralizing amines.

4.3.2 Recommendation

It is recommended that users of this product maintain a residual of 2-3 ppm active ingredient for effective corrosion inhibition.

Acronyms and Abbreviations

Term	Spellout
ANSI	American National Standards Institute
AOX	adsorbable organically bound halogens
BF	bacteria and fungi
BZT	benzotriazole
CERL	Construction Engineering Research Laboratory
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
FORSCOM	U.S. Army Forces Command
HEDP	1-Hydroxyethane
HQDA	Headquarters, Department of the Army
HVAC	heating, ventilating, and air conditioning
IMA	Installation Management Agency
ISWS	Illinois State Water Survey
LSI	Langlier's Saturation Index
NSN	National Supply Number
OMB	Office of Management and Budget
PASP	polyaspartate
PBTC	2-Phosphonobutane-1,2,4-Tricarboxylic Acid
POC	point of contact
RSI	Ryznar's Stability Index
SS	Stainless Steel
TDS	total dissolved solids
THPS	tetrakis
TR	Technical Report
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
WWW	World Wide Web

Appendix A: Acknowledgements

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14. ABSTRACT

The development of current selection and application guidance is necessary to help Army installations be “smart buyers” of water treatment for new and existing heating and cooling systems. Manufacturers continue to introduce new chemicals and treatment programs onto the market, including environmentally friendly “green” chemical products, as old products are discontinued. These products require periodic review to inform Army installations of new technological advances, and of the capabilities of chemical products available in the market-place.

This work demonstrated and evaluated the performance of primary water treatment formulations at Fort Stewart, GA and Fort Hood, TX, using three “green” chemical technologies: (1) the cooling water inhibitor polyaspartate (PASP), (2) the cooling water biocide tetrakis (hy-droxymethyl) phosphonium sul-fate (THPS), and (3) a filming inhibitor made from exthoxalated soya amines (for steam line treatment). The study concluded that the three technologies were effective when used according to the recommended application guidelines.

15. SUBJECT TERMS

Ft. Stewart, GA	Ft. Hood, TX	cooling systems	environmental management
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